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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A structured design process was applied to the design of the F-16 Aircraft Emergency Power Unit (EPU) Service Stand. Explicit steps in the accomplishment of a set of candidate systems, development of a multi-attribute criteria function along with the attendant parameters and their feasible ranges, and the ordinal ranking of the candidate systems in order of preference were accomplished. An exploration of the design space was made to identify the parameter values which would yield the maximum theoretic →

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value of the criteria function for this design space and the results compared with the highest ranked candidate system. During the design of the Service Stand, no unusual emphasis on Human Factors was made with the design engineers, but the results indicate strong acceptance of human factors and human resource limitations when the problem definition is adequetely structured for the designers.

APPLICATION OF A STRUCTURED DECISION PROCESS FOR PROPER INCLUSION OF HUMAN RESOURCES IN THE DESIGN OF A POWER UNIT SUPPORT STAND

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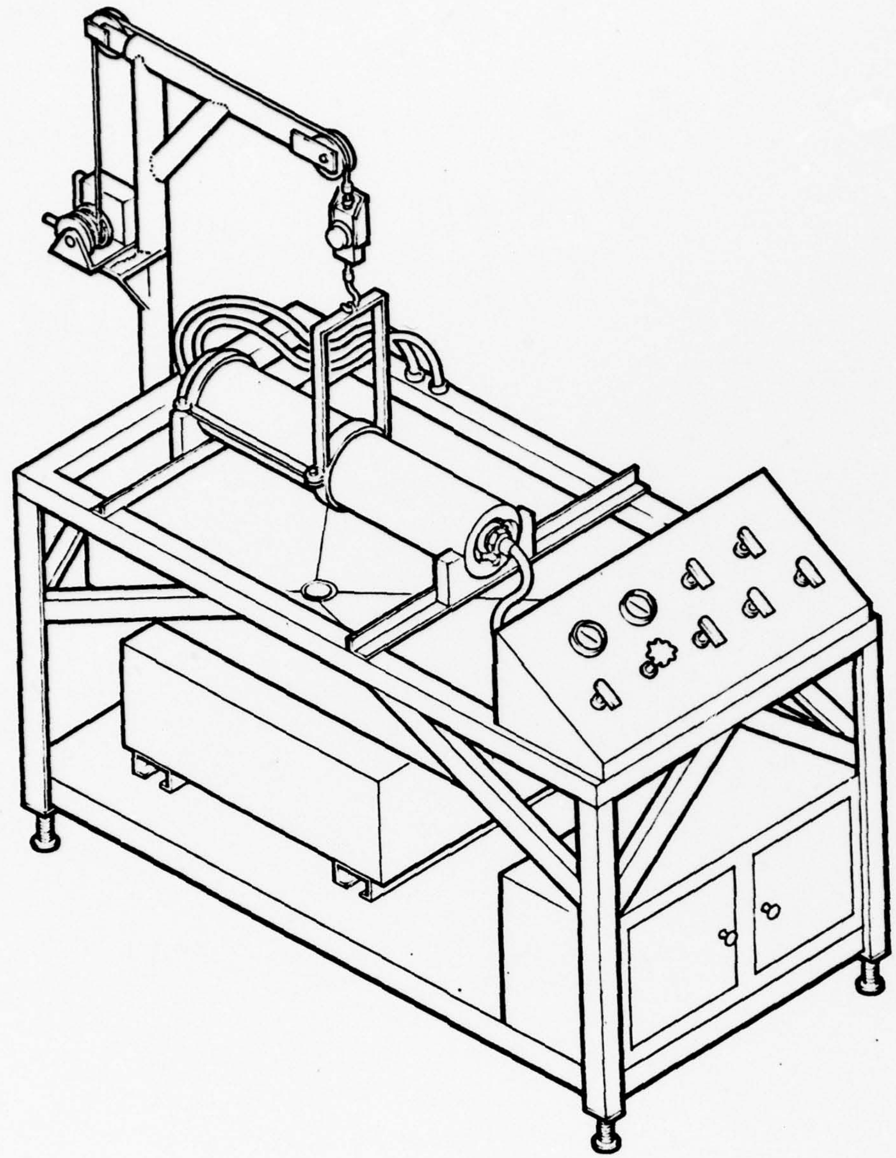

F-16 EMERGENCY POWER UNIT SERVICE STAND
(COURTESY OF GENERAL DYNAMICS, FORT WORTH DIVISION)

ABSTRACT

A structured design process was applied to the design of the F-16 Aircraft Emergency Power Unit (EPU) Service Stand. Explicit steps in the accomplishment of a set of candidate systems, development of a multi-attribute criteria function along with the attendant parameters and their feasible ranges, and the ordinal ranking of the candidate systems in order of preference were accomplished. An exploration of the design space was made to identify the parameter values which would yield the maximum theoretic value of the criteria function for this design space and the results compared with the highest ranked candidate system. During the design of the Service Stand, no unusual emphasis on human factors was made with the design engineers, but the results indicate strong acceptance of human factors and human resource limitations when the problem definition is adequately structured for the designers.

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This research would not have been possible without the assistance and cooperation of many individuals and several agencies. First, the financial support of AFOSR is gratefully acknowledged. Dr. Alfred R. Fregly, Program Manager, Life Sciences Directorate of that agency was helpful with his guidance and Dr. William B. Askren of AFHRL/WPAFB for his technical monitorship of the research and help in providing direction for the research.

Dr. George Webb, Vice President Engineering at General Dynamics, Inc., Fort Worth Division provided access to the F-16 Support Equipment group. His managers Messrs. Gene Heiser, George C. Sumner, and Jack C. Mathews provided the technical support and test bed for accomplishing the activities and developing the information described herein. Further Messrs. Joseph Benoit and Mark Doremus, design engineers in the Support Equipment Group worked with the Principal Investigator to complete the Feasibility Studies and Preliminary Design activities described in this study.

Assistance at the University of Houston was provided as follows:

1. E. A. Kiessling, Col. USAF (ret.), Research Associate for his technical and administrative assistance in the operations of the research contract and the actual problem solution.
2. Capt. John R. Folkeson, USAF, and Qamar Rehmani, Research Assistants, for their help in the programming of the optimization package to analyze the design space and achieve a vector of parameters that optimized the Criteria Function.

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1.0 INTRODUCTION

1.1 Purpose

The purpose of this study was to demonstrate the inclusion of human factors while applying the principles identified in a structured, decision process to the design activities of an article of aerospace equipment. This report summarizes the activity in the second year of a research program[1] to include human factors in their proper perspective during the design of aerospace equipment.

1.2 Scope

This study reports on the application of the design morphology as delineated by Ostrofsky[(1)] to the development of the Emergency Power Unit (EPU) Service Stand for the General Dynamics F-16 Aircraft. The purpose of this effort was to assure the proper emphasis on human factors. The Feasibility Study and Preliminary Design activities were accomplished, resulting in specific configuration requirements for the optimal system and the identification of the potential growth of its effectiveness for the stated design conditions. The activities were accomplished by working directly with the General Dynamics designers[2] in completing each morphological decision through to final optimization. Excellent support was afforded by the General Dynamics engineering management[3] throughout the activities.

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[1]Contract No. AFOSR-F49620-77-C-0116

[2]The contributions of Mr. Mark Doremus and Mr. Joseph Benoit, Support Equipment Design, General Dynamics, Fort Worth, are acknowledged. Without their contributions this study would not have happened.

[3]Mr. Jack Mathews, Mr. George Summer, Manager, Support Equipment Design, Mr. Gene Heizer, Director, Dr. George Webb, Vice President, Engineering and many others directly aided in accomplishing the required work.

1.3 Background

Initial interest was exhibited by the Human Resources Laboratory at Wright Patterson Air Force Base in the continuing problems associated with the proper inclusion of human factors by aerospace equipment designers. While technological problems were usually solved in most sophisticated equipment development, the problems in doing this generally caused designers to overlook, or at best minimize the "softer" areas of design. That is, areas related to the operational environment that dealt with human task capability, as well as the conditions affecting that capability, were often neglected or down-graded to a status that adversely affected performance when the equipment became operational. Corrections, changes, and/or retrofits at this time becomes very costly, particularly when earlier awareness usually entails little additional cost. The design morphology as originally described by Asimow[(2)] and subsequently enhanced by Ostrofsky[(1)] appeared to be a productive approach to the proper integration of this broad set of requirements resulting from many diverse and usually conflicting requirements.

A review[4] was made of the human factors and design literature[(3)] in 1977. The final report[(4)] summarized the design morphology and related it to current USAF methods for managing system design, defining and classifying human factors which influence the decision structure of design, and clarifying the nature of subjective and objective requirements which are inputs to the decision structure. The conceptual framework for the effective approach to the solution of the problem of human factors inclusion into the design morphology was that of a three dimensional matrix representing the relationship among human factors, the design steps, and the current literature.

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[4]USAF/OSR Grant #77-3148

This relationship allows explicit human factors inclusion during the preliminary design activities of a new system and the resultant inclusion in the criteria function for the optimal design configuration. Since the task of human factors inclusion was so large in scope, the study was limited to the accomplishment of several phases of the design process in an attempt to show relevance to the entire process.

1.4 The Design Morphology

Figure 1 identifies the major phases in the life of a technological system[5] and suggests two major sets of phases, the primary design - planning phases and those of the production - consumption cycle. These latter phases represent the activities in actually producing, developing, operating, and retiring the system from service. The former, primary design-planning phases delineate the activities and the attendant decisions needed to anticipate all requirements for the production consumption phases. Hence the design-planning phases can be viewed as being necessary only to accomplish the production - operations phases in an efficient manner.

The purpose of the Feasibility Study is to define the design problem in such a manner as to "bound" the problem in all recognized areas and to structure a set of candidate systems.[6] The Preliminary Design Phase, then has for its purpose the identification of the optimal[7] candidate system. that is, the candidate system that provides the "best" performance of the set of candidates defined as measured against a set of defined criteria and their

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[5]Reference (1) page 18.

[6]Op. Cit. pages 15, 47.

[7]Op. Cit. page 79

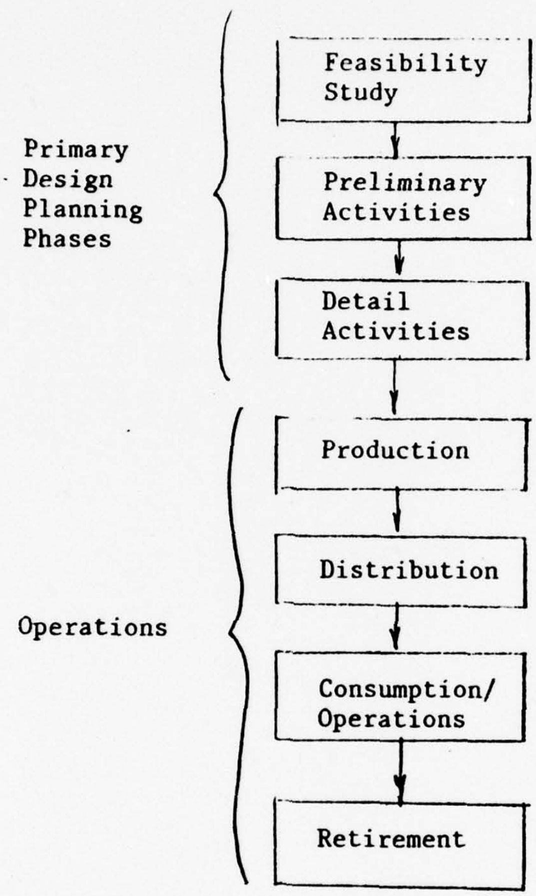

Figure 1. Phases of the designer-planner project life.

respective, relative importances. "Best" is defined from the criteria and the means by which the candidate system performance is measured against these criteria in multiple criterion function. The Detail Design phase[8] then has for its purpose the accomplishment of the detailed planning that should occur to adequately accomplish the required tasks and to meet the problems posed in the production - consumption phases.

The study at General Dynamics/Fort Worth accomplished the activities of the Feasibility Study and the Preliminary Activities.

1.5 Human Resources and Logistics Considerations

Earlier study[(4)] identified the need to define means for including human factors and other subjective inputs into the design optimization process. This study related each of the human factors areas to the respective step in the design morphology in an attempt to clarify those human factor elements that are dominant in each design phase. Hence proper emphasis can be given to each element during the respective design activity. The results of this earlier activity were considered by the designer, and F-16 information was used to develop a multiple criterion function.

In application these considerations were explicit in the determination of design criteria and the manner in which these criteria were estimated from their elements. In fact the design optimization procedures delineated by Ostrofsky[(1)] causes an explicit consideration of all elements defined to be of importance to the assessment of a candidate's performance (as defined by the design criteria). The designer is forced to assess the importance of "softer" elements along with the others in an explicit manner and, more importantly,

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[8] Op. Cit pages 155-243

record his assessments. This record subsequently provides the designer with a formal means for reexamining his decisions in the light of new knowledge or information. This notion of improvement or optimization to assure inclusion of human factors has long been recognized as important. "The goal of the human engineer working with design of a traditional system is largely one of improvement or optimization."[9] Moreover, the notion of a conceptual structure during the design of a system is helpful to understanding the relationships of human engineering to the total system engineering process.[10] Hence it is in this vein that the design of the EPU Service Stand was used as the test vehicle to demonstrate that proper equipment design would include the human resources and factors appropriately when the design is accomplished using the suggested morphology.

2.0 FEASIBILITY STUDY

2.1 Needs and Requirements

The document providing the initial design requirement was Support Equipment Recommendation Data[11] (SERD: 24010). This General Dynamics document indicated a requirement to service the F-16 Emergency Power Unit (EPU) fuel tank with H-70 Hydrazine and provided several design conditions.

The initial activity was the development of an operational flow chart that delineated all tasks required for servicing the EPU fuel tank (See Figure 2). This served the purpose of scoping the activities required for the tank in the F-16 aircraft and compared the SERD recommendations with those activities.

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[9]Reference (5) page 2.

[10]Op-Cit pages 3 and 4.

[11]See Appendix 1

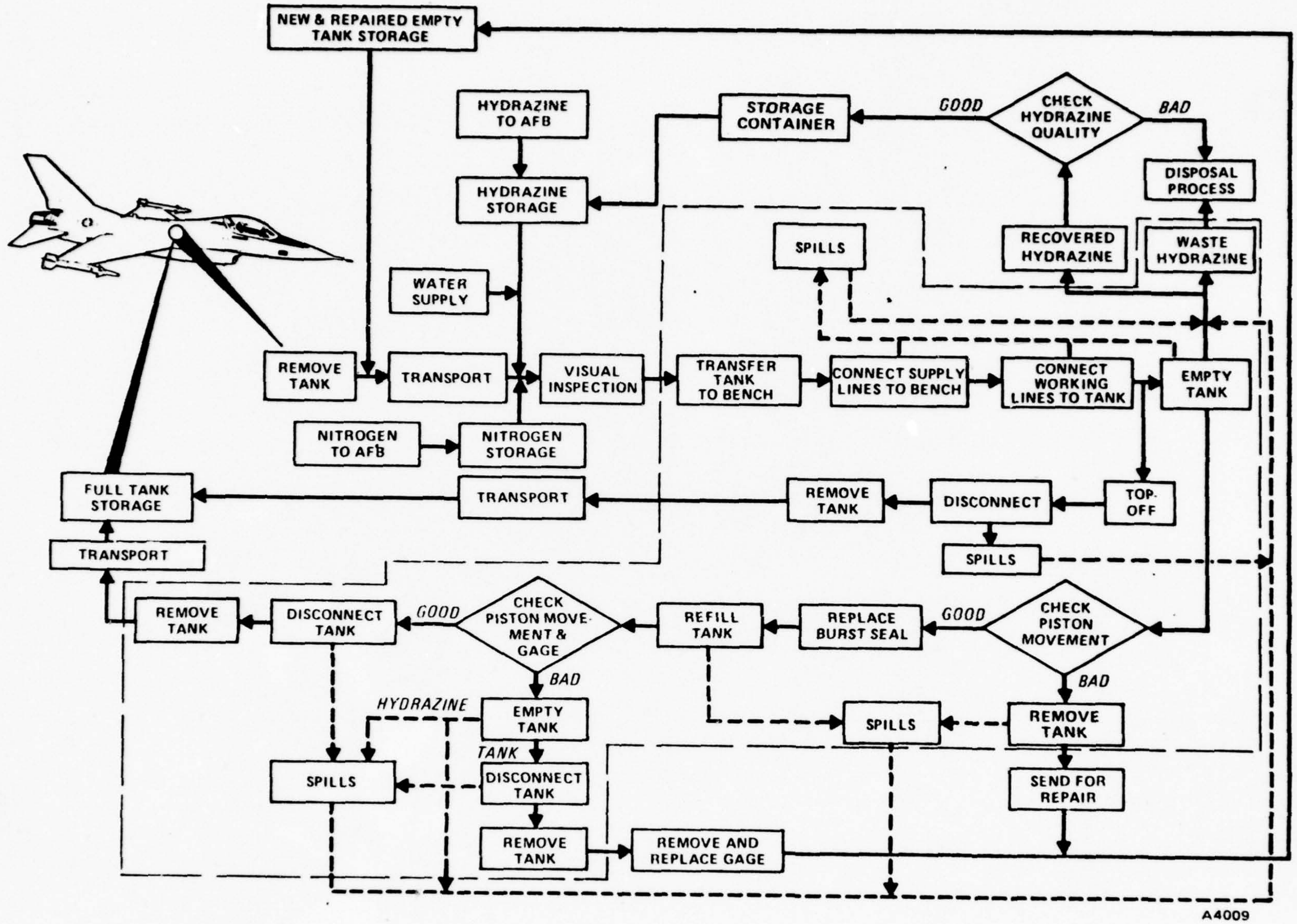

FIGURE 2: OPERATIONAL FLOW CHART

The observation was made that the SERD recommendations did not consider ingress and egress activities of the tank in the aircraft as well as transport to and from the service stand. Hence these tasks require separate developmental activities.

2.2 Identification and Formulation of the Problem

The purpose of this step was to subjectively bound the design requirements in order to efficiently proceed to the choice of the most effective solution that meets these requirements. This was accomplished by considering the respective phases of the Production - Operations cycle in an organized, a priori manner. An input - output format established for each phase and narrative descriptors were identified for each respective cell in the matrix. As observed from figures 3, 4, 5, and 6 the descriptors are so broad in nature that they virtually can be applied to most equipment design. However, the formality of accomplishing these matrices by the designers induces considerable awareness of the major problems to be approached. Moreover, experience shows that most designers do not formally accomplish such study without some sort of predefined format. Figures 3 through 6 provide the results of the designer input - output considerations. Notice the awareness at this point of the broad influences of human factors in each phase of the production operations cycle, and the importance of safety in the handling activities.

Approaching the input - output matrix in this elementary manner served to alert the designer to the major considerations for his equipment in the planned environment. The effort devoted to these matrices was very limited since the nature of the equipment was relatively unsophisticated. However, should areas of concern arise during such studies, an independent study

PRODUCTION

INTENDED	ENVIRONMENT	DESIRED	UNDESIRED
PLANNING AND SCHEDULING	GOV'T PAPERWORK AEI & SPEC LIST	LOW COST	SPECIAL TOOLING
MATERIALS	SPO DESIGN REVIEW	SAFE	SPECIAL SKILLS
MANUFACTURING PROCESSES	SPECIAL EQUIPMENT	SUFFICIENT CAPACITY	SPECIAL EQUIP
SAFETY PROVISIONS (i.e.: Water, Calcium Hypoclorite)	LEAD TIME-SCHEDULE	GOOD QUALITY	SPECIAL MATL
	LEAD TIME-PARTS	FEW COMPLEX ASSYS	
	APPROVAL OF SAFETY ENGINEERING	WELD VS BOLT ASSY DECISION	

DEFINE PROBLEM

FIGURE 3: PRODUCTION PHASE INPUT-OUTPUT MATRIX

DISTRIBUTION

INTENDED	ENVIRONMENT	DESIRED	UNDESIRED
DEPLOYMENT PLAN INTEGRATED LOGISTICS PLANNING TRANING FOR H-70 HANDLING INTERNATIONAL CONCERNS (EPG ETC) EASY TO HANDLE EASY TO TRANSPORT TRAINING FOR USE AND REPAIR OF EQUIPMENT	ROUGH HANDLING PACKAGING SPECS COMMERCIAL CARRIER	SAFETY IN HANDLING ALL PARTS READY AT SAME TIME UNIT IS COMPLETE	LATE OR UNSATISFATORY EQUIPMENT BULKY-REQUIRING SPECIAL HANDLING

FIGURE 4: DISTRIBUTION PHASE INPUT-OUTPUT MATRIX

OPERATIONS

INTENDED	ENVIRONMENT	DESIRED	UNDESIRED
WATER SUPPLY TRAINING FOR H-70 HANDLING NITROGEN SUPPLY H-70 SUPPLY TRAIN FOR SYSTEM OPERATION TECH DATA	SERVING INSTRUCTIONS OPERATING RESTRICTIONS 1. VENTILATED AREA 2. RUNNING WATER 3. BREATHING APPARATUS 4. EXISTING SAFETY INSTRUCTIONS (SEE SPEC LIST) 5. GLOVES TIME LIMIT	PROVIDE EPU TANK SERVICING SHOP EASE OF USE: 1. LARGE-EASY TO READ DIALS 2. EASY TO GRASP HANDLES & KNOBS (WHILE WEARING GLOVES) 3. KNOBS AND DIALS, GROUPED TOGETHER WELL LABELED NON-COMPLICATED INSTRUCTIONS	SPECIAL CLOTHING SPECIAL EQUIPMENT BREAK DOWNS HYDRAZINE INJURIES OTHER OPERATING INJURIES

FIGURE 5: OPERATIONS PHASE INPUT-OUTPUT MATRIX

RETIREMENT

INTENDED	ENVIRONMENT	DESIRED	UNDESIRED
USE FOR F-16 PROGRAM OR LIFE OF PRESENT EPU SYSTEM REVIEW POSSIBLE FUTURE APPLICATIONS REPLACE WEAK SUBSYSTEMS	FLUCTUATIONS IN SCRAP MARKET REQUIRED STORAGE FACILITIES WITH PROPER SAFETY FEATURES	SELL FOR SCRAP OR MELT DOWN RECYCLE METAL AND PARTS USE FOR OTHER SYSTEM OR PROGRAM	POLUTION PROBLEMS WITH RETIREMENT

FIGURE 6: RETIREMENT PHASE INPUT-OUTPUT MATRIX

activity could be accomplished to clarify the problem definition. Such studies were not needed for the EPU Service Stand.

2.3 Concept Formulation

A design concept is defined[12] as a basic approach toward solving the requirements problem, while a candidate system[13] is a particular alternative of the given concept. Figure 2, the flow diagram representing the activities for the EPU Service Stand has already defined both the activities and the major decisions in the flow sequence. The concept, then, is simply the delineation of the equipment functions at the level usable by the designer to define configurations. Obviously, there are many concepts to solve a given equipment design problem, the number growing exponentially with the number of equipment functions defined. Figure 7 presents the formal "concept" pursued in this design.

2.4 Development of Candidate Systems

Candidate systems are developed by considering each equipment function independently and exhaustively listing the alternatives for them. A candidate system can then be defined by combining one alternative from each of the concept functions such that every function defined would be accomplished if this combination of alternatives could be realized. Figure 8 shows the result of defining alternative methods for accomplishing each function and identifies over 3.8 billion combinations, a number too large to consider evaluating each one separately.

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[12]Op. Cit. p. 47.

[13]Op. Cit. p. 47

IDENTIFICATION OF FUNCTIONS

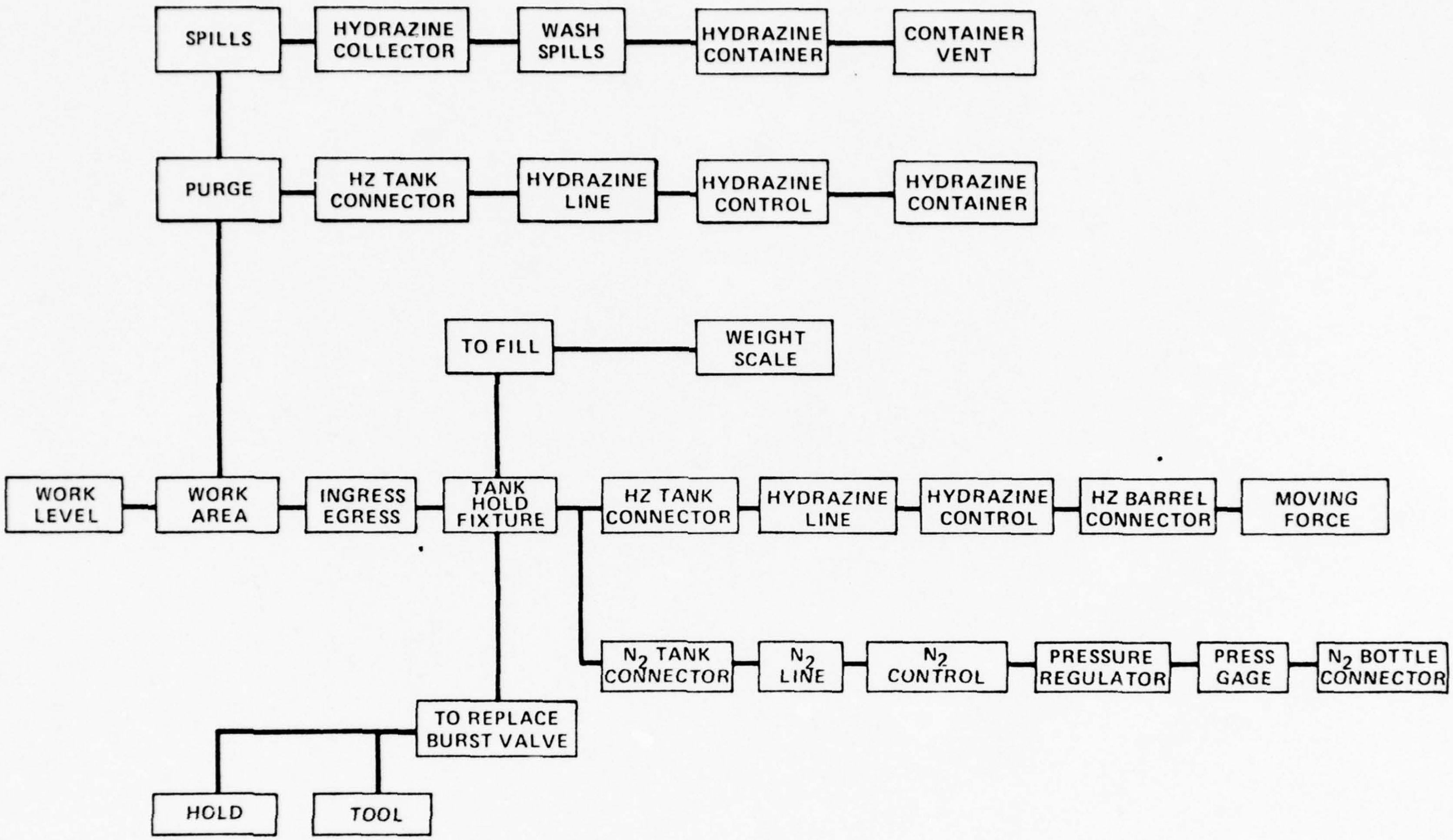

FIGURE 7: FORMAL CONCEPT FOR THE DESIGN

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IDENTIFICATION OF FUNCTIONAL CANDIDATES

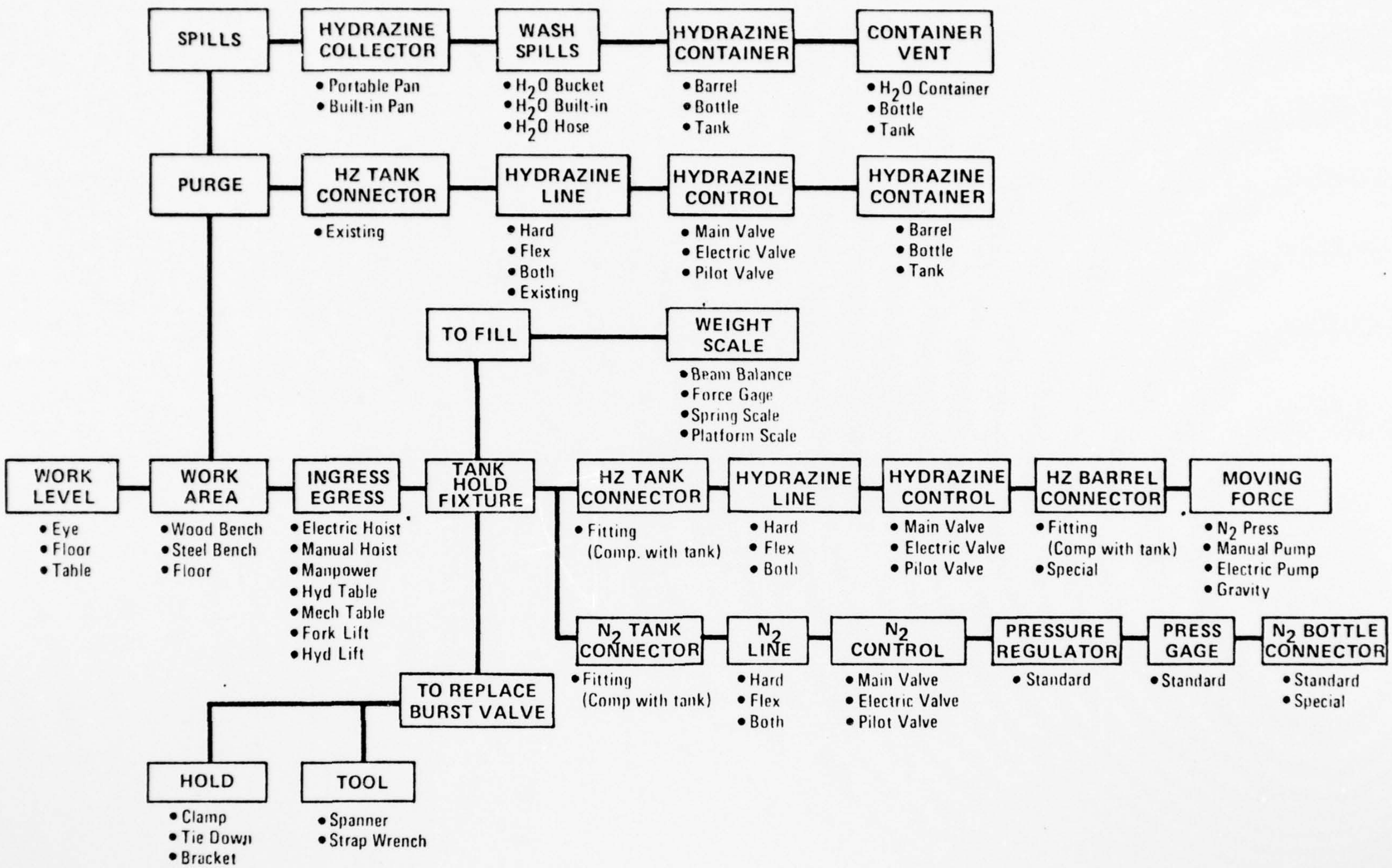

FIGURE 8: IDENTIFICATION OF ALTERNATIVES

After some study the designers were able to intuitively eliminate more costly alternatives, leaving those that were obviously desireable as well as those that were questionable. Only the most undesireable or infeasible combinations were eliminated. After this screening there were 128 candidate systems[14] remaining, and this set provided the basis for the subsequent choice of the optimal configuration. (See Figure 9).

3.0 PRELIMINARY DESIGN ACTIVITIES

3.1 Definition of Criteria $\{x_i\}$ and their Relative Importance $\{a_i\}$.

The preliminary design activities have for their purpose the definition of the optimal candidate system.[15] Since the set of candidates to be studied has already been defined in the Feasibility Study, this Preliminary Design encompasses the activities required to define and to analyze the design space[16] formed by the emerging design parameters and the criterion function synthesized to evaluate candidate system performance.[17]

The initial task is the explicit definition of the criteria against which the candidate systems will be evaluated. From study of the SERD (see Appendix I) and the input-output matrix of Figures 3, 4, 5, and 6 the criteria of Table 1 were identified.

A survey of the support equipment design management at General Dynamics imparted the relative weights indicated in Table I below:

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[14]Actually there are 256 candidate systems shown on the diagram, but the nitrogen control value was on an existing tank and is manual, therefore the alternative "pilot valve" was not considered.

[15]Op. Cit. page 69.

[16]Op. Cit. page 128.

[17]Op. Cit. pages 95-116

IDENTIFICATION OF FUNCTIONS

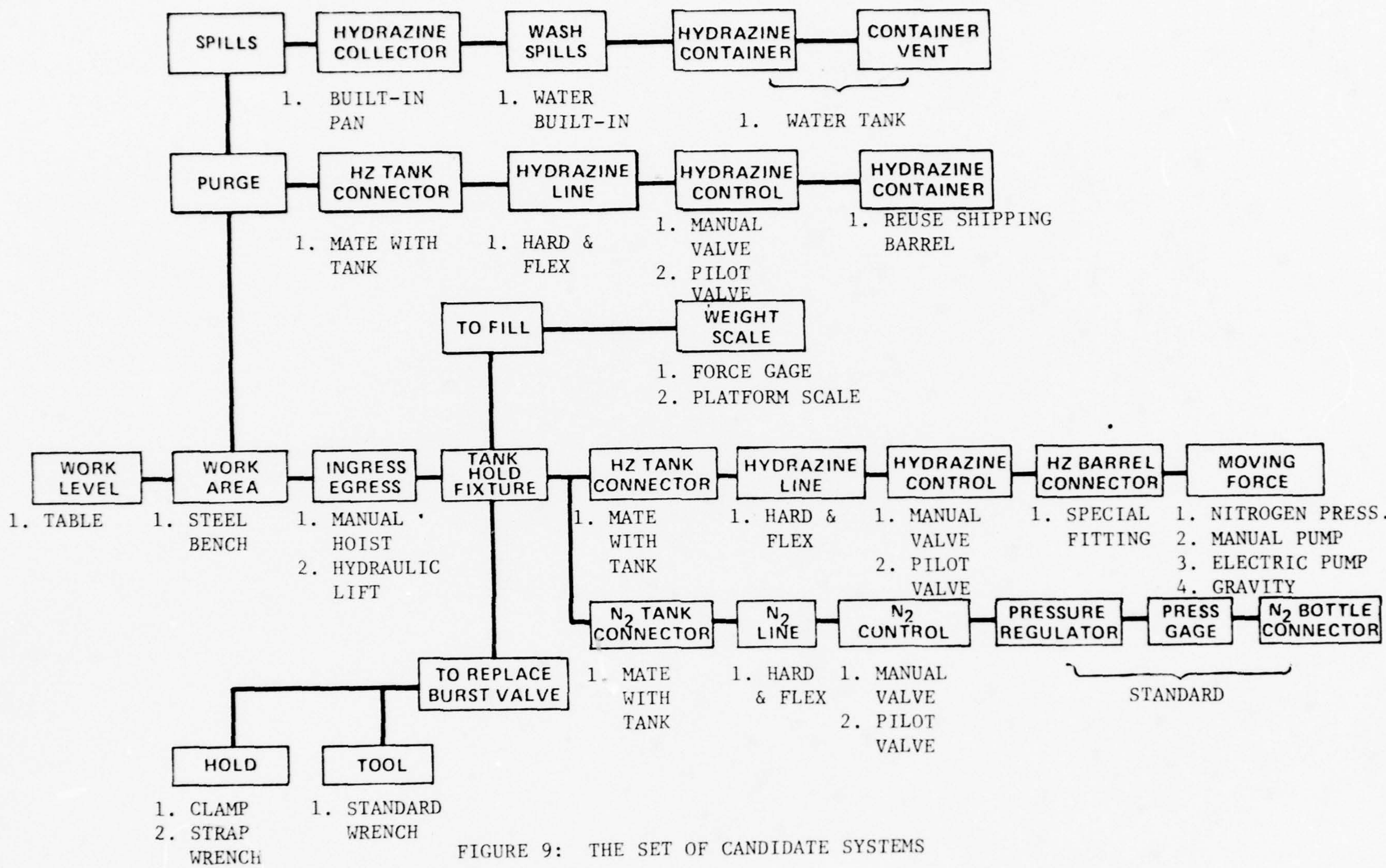

FIGURE 9: THE SET OF CANDIDATE SYSTEMS

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TABLE I

CRITERIA & RELATIVE WEIGHTS

Criteria $\{x_i\}$	Relative Weight $\{a_i\}$
1. Safety	.318
2. Cost	.122
3. Ease of Use	.174
4. Durability	.126
5. Producability	.122
6. Availability	.138
	1.000

At this point the criteria have been defined narratively, and must be further developed to permit the required precision in comparing the performance of the various candidate systems. This development process will impart precise semantics to the meaning of each criterion, and the precision will result from the process of quantifying (or modeling) that will relate each criterion to the characteristics of the equipment. These characteristics are further identified as submodels and parameters, and are discussed below.

3.2 Definition of Design Parameters $\{y_k\}$.

Each criterion was then analyzed for constituent elements that would help define that criterion in terms that relate to the design equipment and its environment.[18] These elements then serve to define the criterion explicitly for this design optimization. For example, the criterion Safety (See Table II) has been defined in terms of the elements Ease of Maneuvering, Weight of the Fuel Tank, Volume of Tank, Arrangement of Controls, and Probability of Leakage. An assessment was then made of the most effective manner in which to quantify each of these elements using the codes as follows:[19]

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[18]Op. Cit. page 86-94.

[19]Op. Cit. page 89.

TABLE II. CRITERIA AND ELEMENTS

SAFETY	CODE
EASE OF MANEUVERING	B
WEIGHT OF FULL TANK	A
VOLUME OF FULL TANK	A
ARRANGEMENT OF CONTROLS	D
PROBABILITY OF LEAKAGE	B
COST	
MEAN COST PER PURCHASED PARTS	A
TIME REQUIRED FOR ASSEMBLY	A
NUMBER OF PURCHASED PARTS	A
OVERHEAD RATE	A
LEARNING CURVE	A
NUMBER OF UNITS BUILT	A
TOTAL NUMBER OF PARTS	A
COST OF MANUFACTURING TIME	A
EASE OF USE	
SIMPLICITY OF PROCEDURES	A
READABILITY OF GAGES	A
SIMPLICITY OF WASTE DISPOSAL TASKS	A
MANHOURS PER SERVICING EPU TANK	A
WEIGHT OF TANK	A
VOLUME OF TANK	A

DURABILITY	CODE
EASE OF SHIPMENTS	A
NUMBER OF OPERATING CYCLES	B
PRODUCABILITY	
TOTAL NUMBER OF PARTS	A
NUMBER OF PURCHASED PARTS	A
AVAILABILITY	
TIME TO MAINTAIN STAND PER DAY	A

A. directly measured

B. measured from a model that includes some of the a's

C. completely included in other elements

D. *not measurable within existing resources*

Table III shows the elements identified in Table II as they relate to each submodel and criterion. This arrangement provides increased visability to the accomplishment of completeness and compactness[20] studies and is helpful toward the assurance of consistency among the parameters.

3.3 Modeling the Criteria

Basically the methods described[1] in Chapter 12 were used. The models serve to attribute semantics to each criterion, and each is defined in terms of the relationships and assumptions delineated in the modeling exercise.

3.3.1 Safety, x_1

3.3.1.1 Assumptions

1. The area is ventilated to some specified flow rate (air changes)

2. *There will be adequate protective gear on personnel*

3.3.1.2 Submodels and Parameters

z_1 = Ease of Maneuvering the EPU tank

z_2 = Probability of no leakage from the connectors

y_1 = number of connectors in the lines

y_2 = weight in pounds of tank and H-70

C_1 = Volume of EPU tank, 1.41 ft^3

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[20] Op. Cit pages 80,91.

TABLE III: CRITERIA, SUBMODELS, AND PARAMETERS

	1 SAFETY		2 COST	3 EASE OF USE		4 DURABILITY		5 PRODUCABILITY	6 AVAILABILITY
PARAMETERS Y_K	EASE OF MANEUVERING	PROBILITY OF LEAKAGE		MANHOURS FOR SERVICING TANK	EASE OF MANEUVERING	NUMBER OF OPERATING CYCLES	EASE OF SHIPMENT		TIME TO MAINTAIN STAND
1. NO. OF CONNECTORS		X							
2. WEIGHT OF TANK & H-70	X				X				
3. PRODUCTION MANHOURS PER UNIT			X						
4. MEAN COST PER PURCHASED PART			X						
5. MANHOURS FOR SERVICING EPU TANK				X					
6. SIMPLICITY OF PROCEDURES				X					
7. READABILITY OF GAGES				X					
8. SIMPLICITY OF WASTE DISPOSAL TASK				X					
9. EASE OF SHIPMENT							X		
10. LIFE OF F-16 PROGRAM						X			
11. NO. OF PURCHASED PARTS			X					X	
12. TIME TO MAINTAIN STAND									X
13. TOTAL NO. OF PARTS								X	
14. A/C FLIGHT HOURS PER MONTH					X				
15. NO. OF A/C PER STAND					X				

3.3.1.3 Ease of Maneuvering the EPU tank, z_1

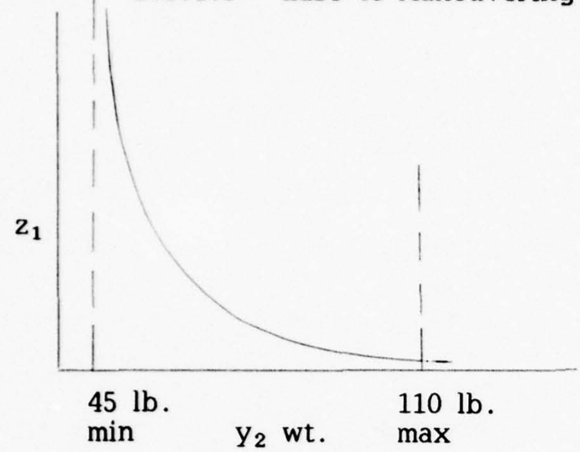

Figure 10. Ease of Maneuvering vs. Wt.

$$z_1 \sim y_2^{-k} \quad \text{(assume } k = 1\text{)} \tag{1}$$

$$z_1 \sim \frac{1}{C_1} \tag{2}$$

$$z_1 = \frac{1}{y_2 C_1} \tag{3}$$

3.3.1.4 Probability of No Leakage from the Connectors, z_2

$$z_2 = (1 - p_1)^{y_1} \tag{4}$$

Equation 4 states that z_2, the probability of no leakage from the connectors depends on p_1, the probability of leakage and y_1, the number of connectors. Inherent in this equation is the assumption of equal probability of leakage (reliability) for each connector. The range from .05 to .15 was estimated by engineering and for purposes of this study and 0.1 was used.

3.3.1.5 The Model for Safety

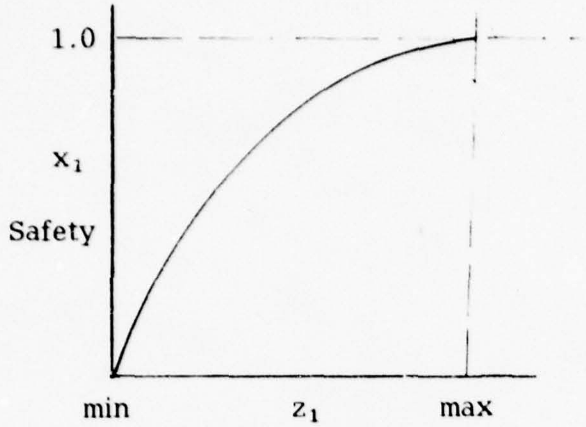

Figure 11. Safety vs. Ease of Maneuvering

From figure 11:

$$x_1^2 = az_1 \tag{5}$$

At z_1 max:

$$1 = a\frac{1}{45(1.41)} = .016a$$

$$a = 62.5$$

$$x' = (62.5z_1)^{\frac{1}{2}} = \left(\frac{62.5}{y_2C_1}\right)^{\frac{1}{2}}$$

For leakage:

Let $x_1'' = z_2$ (6)

Then, assuming independence among submodels:

$$x_1 = z_1{}^{\frac{1}{2}}z_2 \tag{7}$$

$$= \left(\frac{62.5}{y_2C_1}\right)^{\frac{1}{2}} (1 - p_1)^{y_1} \tag{8}$$

When $p_1 = 0.1$

$$x_1 = .9^{y_1} \left(\frac{62.5}{y_2C_1}\right)^{\frac{1}{2}} \tag{9}$$

Hence, one could say that since H-70 is highly toxic and essentially any exposure to the maintenance personnel is dangerous, then the criterion, safety is directly proportional to the probability of no leakage.

3.3.2 Cost, x_2

3.3.2.1 Assumptions

This cost model represents the manufacturing costs at the Contractor for the number of EPU Service Stands to be produced under contract to USAF.

3.3.2.2 Parameters

y_3, production man-hours per unit

y_4, mean cost/purchased part

y_{11}, number of purchased parts

y_{13}, number of total parts

C_2, *number of manufactured parts*

OH, overhead rate

LC = learning curve percentile

N = number to be produced (11)

3.3.2.3 The Cost Model:

$$z' = (y_3C_2 + y_{11}y_4)(O.H.)(L.C.)^N \quad (10)$$

for N = 11:

$$z' = (y_3C_2 + y_{11}y_4)\ (OH)(LC)^N$$

But x_2' is an increasing function and for the criterion "cost," increasing merit implies decreasing cost. Therefore:

$$x_2 = -z \quad (11)$$

gives the characteristic desired for the criterion function and

$$x_2 = -(y_3C_2 + y_{11}y_4)(OH)(LC)^N \quad (12)$$

3.3.3 Ease of Use, x_3

3.3.3.1 Assumptions

Ease of use of the EPU Service Stand is based on the man-hours required to service the EPU tank and the ease of maneuvering the tank for the given Service Stand configuration.

3.3.3.2 Submodels and Parameters

y_2 Weight of tank, 110 pounds, max.

y_5 Man-hours for servicing EPU tank

y_6 Simplicity of procedures

y_7 Readability of gages

y_8 Simplicity of waster disposal tasks

C_1 Volume of EPU tank, 1.41 ft.^{3}

3.3.3.3 The Model for Ease of Use

Let $z' = y_6$

where y_6 is indexed subjectively from 1.0 to 10.0

Let $z'' = y_7$

where y_7 is indexed subjectively from 1.0 to 10.0

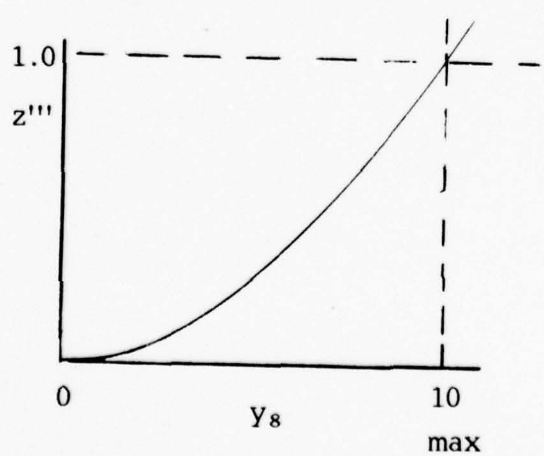

Figure 12 Simplicity of waste disposal task, y_8

$$z''' = (a\ y_8)^{\frac{1}{2}} \tag{13}$$

When $z''' = 1.0$, $y_8 = 10$, then $a = 0.1$

$$z''' = (0.1y_8)^{\frac{1}{2}} = .316y_8^{\frac{1}{2}} \tag{14}$$

Also, Ease of use, x_3 relates inversely to the number of man-hours for servicing the tank, y_5; the weight of the tank, y_2; and the volume of the tank, C_1;

Hence:

$$x_3 = \frac{z'z''z'''}{y_2y_5C_1} \tag{15}$$

or

$$x_3 = \frac{0.316\ y_6y_7y_8^{\frac{1}{2}}}{C_1y_2y_5} \tag{16}$$

3.3.4 Durability, x_4

3.3.4.1 Assumptions

Durability is defined in terms of the life of the F-16 program, ease of shipment, rate of flight hours/month for the aircraft, and the planned number of aircraft serviced per stand.

3.3.4.2 Submodels and Parameters

y_9 = Ease of Shipment

y_{10} = Life of F-16 Program in Months

y_{14} = Flight hours per month

y_{15} = No. of Aircraft Per Service Stand

k_1 = 2500 hours per in-flight firings

k_2 = 2778 hours per functional test

k_3 = 400 hours per operational test

L_1 = 15 accidental firings/month

L_2 = 0.73 accidental maintenance firings/month

L_3 = one spare prepared per month

3.3.4.3 Ease of Shipment, y_9

Let $z' = y_9^{-2}$, where y_9 is indexed on a scale from 1.0 to 10.0 where 10 is the most difficult shipment.

3.3.4.4 Number of Operating Cycles

Number of Operating Cycles =

$$z'' = y_{10} \{(y_{14} y_{15} + \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + L_1 + L_2 + L_3)\} \quad (17)$$

3.3.4.5 Durability Model

$$x_4 = z' \cdot z''$$

$$= \frac{y_{10}}{y_9^2} \{(y_{14} y_{15} + \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + L_1 + L_2 + L_3)\} \quad (18)$$

3.3.5 Producability, x_5

Producability is defined to be the fraction of the total number of parts that are purchased from the vendor.

or:

$$x_5 = \frac{y_{11}}{y_{13}} \quad (19)$$

where:

y_{11} is the number of purchased parts

y_{13} is the total number of parts in the Service Stand

3.3.6 Availability, x_6

Availability is defined to be the fraction of the total time that the service stand is available for use:

$$x_6 = 1 - \frac{y_{12}}{T} \quad (20)$$

where

y_{12} is time to maintain stand/day, minutes

T is 24 x 60 or 1440 minutes/day.

3.4 Structure of the Criteria Function

3.4.1 Range of Parameters

In order to prepare for the synthesis of the Criteria Function Table IV was structured. The parameters were defined in section 3.2 and resulted from the elements used to define the criteria (Section 3.1). Note that several of the parameters were held constant for all candidate systems (i.e.: y_2, y_7, y_{10}, y_{14}, y_{15}). These constants were defined in the USAF equipment performance documentation provided General Dynamics and hence no latitude was permitted at this point. However, during the subsequent analyses of the design space these constants were changed in order to observe their affects on the total criteria function.

The observation is made that considerable study was accomplished by the General Dynamics engineers to arrive at meaningful values for the ranges shown in Table IV. It is further observed that additional study might have resulted in additional parameters, but lack of time caused curtailment of this activity.

3.4.2 Range of Criteria

The criteria ranges must be defined to implement the particular form of the criteria function exercised in this study. In order to estimate the maximum and the minimum of each criterion, the criterion models of Section 3.3 were exercised using the appropriate value of each required parameter from Table IV. Hence the submodels were used only to achieve values of the respective criterion, (x_i; $i = 1, . . ., 6$) and Table V resulted. The computation was accomplished with the aid of a computer.[21]

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[21]A software package is currently being developed at the University of Houston to output Table V with Table IV as input values along with the criterion models. See discussion Section 3.5 and 3.6.

TABLE IV RANGE OF PARAMETERS, y_k

k	y_k	minimum	maximum
1	Number of Connectors	61	70
2	Weight of Tank and H-70	-------110-------	
3	Production man-hours per unit	499mh	935mh
4	Mean Cost/Purchased Part	$32.6/part	$40.2/part
5	Man Hours for Servicing EPU tank	2.7mh	8mh
6	Simplicity of Procedures	2	10
7	Readability of Gages	---------3--------	
8	Simplicity of Waste Disposal Task	3	7
9	Ease of Shipment	4	15
10	Life of F-16 Program	-------300-------	
11	Number of Purchased Parts	93	103
12	Time to maintain Stand	1.38 min/day	1.65 min/day
13	Total Number of Parts	142	173
14	Aircraft Flight Hours/Month	--------30-------	
15	Number of Aircraft/Stand	--------72-------	

3.4.3 Synthesis of Criteria Function

In order to adequately compare the candidate systems, the relative weights, a_i, and the criteria, x_i, must be synthesized into a single function so that a figure of merit can emerge. This figure of merit represents the performance of a given candidate system when a particular alternative yields y_k, the set of parameters representing 'that particular configuration.

When the criteria x_i are examined,[22] it becomes clear that some way of handling the criterion units must be included in the function. For example, x_i, safety is measured in units of probability, volume, and weight; x_2 is measured in inverse of dollars, x_3 is on a subjective scale, etc. Hence some method for relating the sensitivity of the unit value of x_1 with the unit value of each remaining x_i must be used. If this is accomplished improperly, the resulting combination of these criteria will not be meaningful.

A basic consideration is that the criterion function is the vehicle for comparing the values resulting from the candidate systems. Hence a requirement for this function is that it should present the performance of a candidate for its parameters in units that are consistent for all criteria. Such a vehicle is obtained by identifying criterion performance as a fraction of the allowable range for that criterion:

$$X_i = \frac{x_i - x_{i\,min}}{x_{i\,max} - x_{i\,min}} \tag{20}$$

Here X_i represents the i^{th} criterion performance of a given candidate system, hence the numerator represents the "distance" from the minimum value of x_i

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[22]Op. Cit. p. 113.

that a *given candidate system* yields *for* that respective x_i, and the denominator is the range of the criterion's performance. Hence equation 20 represents the fraction of the criterion range that a given candidate system will yield as its performance.

When this fraction is given its relative importance, a_i, the product $a_i X_i$ represents the weighted or relative value of the $i^{\underline{th}}$ criterion. These can be added to give:

$$CF_\alpha = \sum_{i=1}^{6} a_i X_i \tag{21}$$

where CF_α = the value of the criterion function for the α candidate system.

There now exists a method for assessing the performance of the candidate system when parameter values are identified since

$$x_i = f_i \ \{z_i\} \tag{22}$$

and

$$z_i = g_i \ \{y_k\} \tag{23}$$

hence

$$x_i = f_i \ \{g_i \ \{y_k\}\} \tag{24}$$

From equations[23] 21 and 24:

$$CF_\alpha = \sum_{i=1}^{6} a_i \left[\frac{f_i \ \{g_i \ \{y_k\}\} - x_{i\ min}}{x_{i\ max} - x_{i\ min}}\right] \tag{25}$$

Equation 26 shows equation 25 translated for this particular design problem using the information presented in sections 3.1, 3.2, and 3.3.

Equation 25 and its application, equation 26 represent a simplistic approach to the structure of the criterion function. Its major limitation is the assumption of independence among the criteria. (i.e. Cost independent of safety, availability, etc.) One result of the development of this criterion

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[23]Op. Cit. p. 115.

function is the current study[24] of methods for estimating the criterion interaction effects.

$$CF_{\alpha} = a_1 \frac{\{(\frac{62.5}{y_2C_1})^{\frac{1}{2}} (1 - p_1)^{y_1}\} - x_{1\ min}}{x_{1\ max} - x_{1\ min}}$$

$$+ a_2 \frac{-(y_3C_2 + y_{11}y_4)(OH)(LC)^N - x_{2\ min}}{x_{2\ max} - x_{2\ min}}$$

$$+ a_3 \frac{\frac{.316\ y_6y_7y_8^{\frac{1}{2}}}{y_5y_2C_1} - x_{3\ min}}{x_{3\ max} - x_{3\ min}}$$

$$+ a_4 \frac{\frac{y_{10}}{y_9^2}\{y_{14}y_{15}(\frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3}) + L_1 + L_2 + L_3\} - x_{4\ min}}{x_{4\ max} - x_{4\ min}}$$

$$+ a_5 \frac{\frac{y_{11}}{y_{13}} - x_{5\ min}}{x_{5\ max} - x_{5\ min}}$$

$$+ a_6 \frac{(1 - \frac{y_{12}}{T}) - x_{6\ min};}{x_{6\ max} - x_{6\ min}} \qquad (26)$$

3.5 <u>Analysis of Design Space</u>

3.5.1 Definition of the Design Space

The design space for this problem is a hyperspace in eleven dimensions, one for each parameter and one for the value of the criterion function. The limitations of this space are the regional

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[24]See appendix C of (1); Further study of CF as a multivariate probability function and techniques for estimating the interaction effects by estimating marginal and conditional probability functions are currently under way at the University of Houston.

constraints[25] imposed upon the y_k, that is their respective maximum and minimum values, and the limits of CF_α, zero and one.

3.5.2 Sensitivity Analysis

A study was accomplished to examine the rate of change of CF_α throughout the range of each design parameter. Computer runs were made to compute CF_α throughout the design space in the following manner:

1. Increment y_1 in 10% increments throughout its range holding other y_k at their respective minimums compute CF at each moment.
2. Increment y_2 in 10% increments throughout its range, holding other y_k at their respective minimums, compute CF at each increment.
3. Repeat above for each y_k, holding other y_k at their respective minimums.
4. Repeat steps 1 through 3 holding all remaining parameters at the 25% of the parameter range values.
5. Repeat step 4 for parameter range values of 50%, 75%, 100%.

This procedure resulted in the equivalent of 50 hyperplanes cutting through the design space, thus indicating the nature of the CF_α variation throughout the range of each parameter at 25% intervals of all parameters other than the ones examined. Thus 50 (5 planes @ 10% interval for a given parameter) sets of data were computed. Table VI shows the maximum positive percent change in CF and the minimum percent change for each parameter. This implies a potential variation of the criteria function equal to their difference, and this is shown in the

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[25]Op. Cit. p. 113.

right hand column ($\Delta\%$). Examination of this column reveals that y_1, the number of connectors can change the criterion function as much as 399.5% throughout the design space, and hence, is by far the most critical of all identified parameters to the achievement of maximum performance of the stand as identified by the criteria function, CF_α.

Of equal interest are y_4, mean cost/purchased part, y_8, simplicity of waste disposal and y_{11}, number of purchased parts. The maximum changes in CF_α throughout their entire range in the design space are 10.9%, 25.8%, and 41.9% respectively. Hence changes in these parameters, for the respective ranges identified, have the least effect on the criteria function. Note that y_4 the mean cost or purchased part and y_{11} the number of purchased parts are the two parameters affecting change in CF the least, (least sensitive parameters).

Table VII shows the location in the design space of the maximum percent change. For example, the maximum percent change in CF_α for y_1 occurred when all remaining parameters were held at their maximum values. At this "point" in the design space, a 359.1% change in the CF was observed.

Similarly Table VIII shows where in the design space the minimum (or lowest) percent change in CF_α was located. For example, the minimum percent change in CF_α for y_1 occurred when all remaining parameters were held at the values occurring at the 25% point in their respective range. The change in the criterion function (ΔCF_α) noted was -40.4%. Hence Table VI simply indicates the difference between the minimum and maximum values.

Table VI

Maximum Variation of CF_α

For Each Parameter

k	y_k	Maximum % Change	Minimum % Change	Δ%
1	No. of Connectors	359.1	-40.4	399.5
3	Production Man-Hours/Unit	120.9	-15.9	136.8
4	Mean Cost/Purchased Part	9.7	-1.2	10.9
5	Man Hours/Servicing EPU Tank	132.3	-4.4	136.7
6	Simplicity of Procedures	11.6	-53.9	65.5
8	Simplicity of Waste Disposal	2.5	-23.3	25.8
9	Ease of Shipment	145.9	-16.2	162.1
11	No. of Purchased Parts	5.4	-36.5	41.9
12	Time to Maintain Stand	157.1	-19.9	177.0
13	No. of Total Parts	93.2	-8.6	101.8

Table VII

Maximum % Change in CF_α Throughout

Each Parameter Range

k	Parameter, y_k	% of Range For other Parameters	Maximum % Δ CF_α
1	No. of Connectors	100	359.1
3	Production man-hours per unit	100	120.9
4	Mean Cost/Purchased Part	100	9.7
5	Man Hours for Servicing EPU Tank	100	132.3
6	Simplicity of Procedures	0	11.6
8	Simplicity of Waste Disposal	50	2.5
9	Ease of Shipment	100	145.9
11	No. of Purchased Parts	50	5.4
12	Time to Maintain Stand	100	157.1
13	No. of Total Parts	100	93.2

Table VIII

Minimum % Change in CF_α Throughout

Each Parameter Range

k	Parameter, y_k	% of Range For other Parameters	Minimum % Δ CF_α
1	No. of Connectors	25	-40.4
3	Production Man-Hours Per Unit	50	-15.9
4	Mean Cost/Purchased Part	50	-1.2
5	Man-Hours/Servicing EPU Tank	50	-4.4
6	Simplicity of Procedures	100	-53.9
8	Simplicity of Waste Disposal	100	-23.3
9	Ease of Shipment	0	-16.2
11	No. of Purchased Parts	100	-36.5
12	Time to Maintain Stand	75	-19.9
13	No. of Total Parts	75	-8.6

3.5.3 Aircraft per service stand vs. Flight Hours per month.

The criterion function, once developed presents a closed form function enabling the designer-planner to analyze particular relationships among the parameters and criteria. For example safety and cost can be related at the criterion level. At the parameter levels in CF the number of aircraft per service stand (y_{15}) can be related to aircraft flight hours per month (y_{14}). (See Figure 13). Equation 18 reduces to:

$$y_{14} = \frac{2160}{y_{15}} \tag{27}$$

3.6 Criteria Function Optimization

3.6.1 Optimization Among Candidate Systems

The sensitivity analysis of section 3.5.2 permitted careful study of the design space, and provided insight into the nature of this design space so that when a candidate system is chosen, its implementation can proceed with minimum risk of changing the CF_α sufficiently to remove it from its top rank in the listing of CF_α for the candidate systems defined. Hence the desire to identify minimum and maximum CF_α changes is justified.

In order to proceed, however, the optimal[26] candidate must be identified. To this end equation 26 of Section 3.4 was programmed to compute the CF_α for each of the 128 candidate systems, (see Figure 9) identified in section 2.4. These were ranked in descending order (see Figure 14). Candidate number 9, identified in Figure 15, is the configuration of the service stand that will be developed subject to the resolution of the problems in detail design.

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[26]Op. Cit. page 79; The most desirable of those candidates is considered.

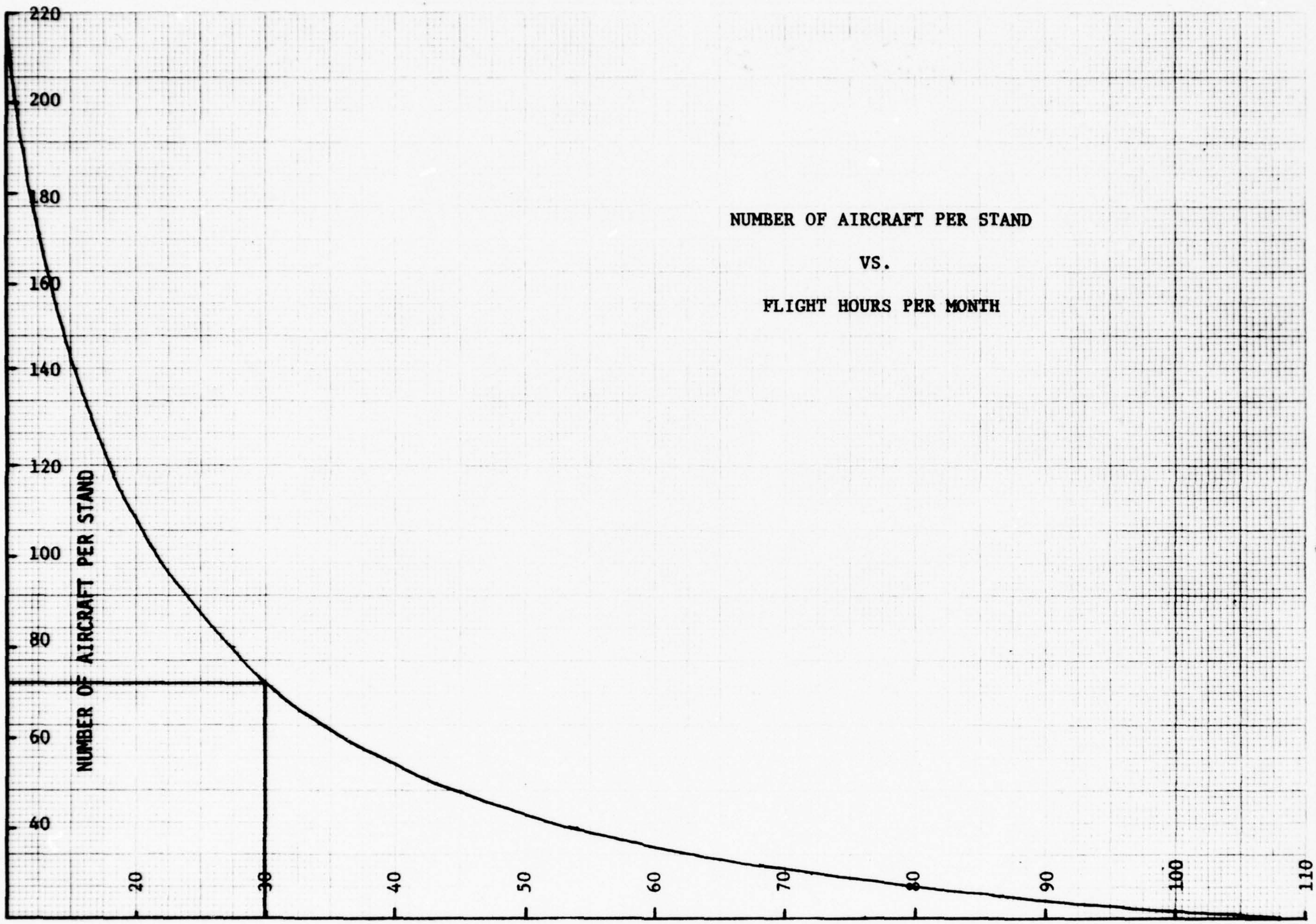

FIGURE 13 FLIGHT HOURS/MONTH

Figure 14: Ranked Candidate Systems

RANK	CANDIDATE	CF VALUE
1	9	0.859
2	1	0.829
3	25	0.779
4	17	0.747
5	10	0.670
6	11	0.667
7	12	0.663
8	13	0.636
9	2	0.636
10	4	0.634
11	65	0.628
12	3	0.628
13	28	0.625
14	41	0.624
15	27	0.617
16	26	0.616
17	5	0.613
18	29	0.613
19	57	0.611
20	73	0.611
21	33	0.603
22	20	0.589
23	49	0.581
24	18	0.570
25	19	0.562
26	81	0.559
27	89	0.554
28	21	0.538
29	44	0.506
30	60	0.501
31	14	0.496
32	52	0.494
33	15	0.493
34	77	0.489
35	66	0.484
36	16	0.479
37	64	0.477
38	67	0.477
39	69	0.476

IDENTIFICATION OF FUNCTIONS

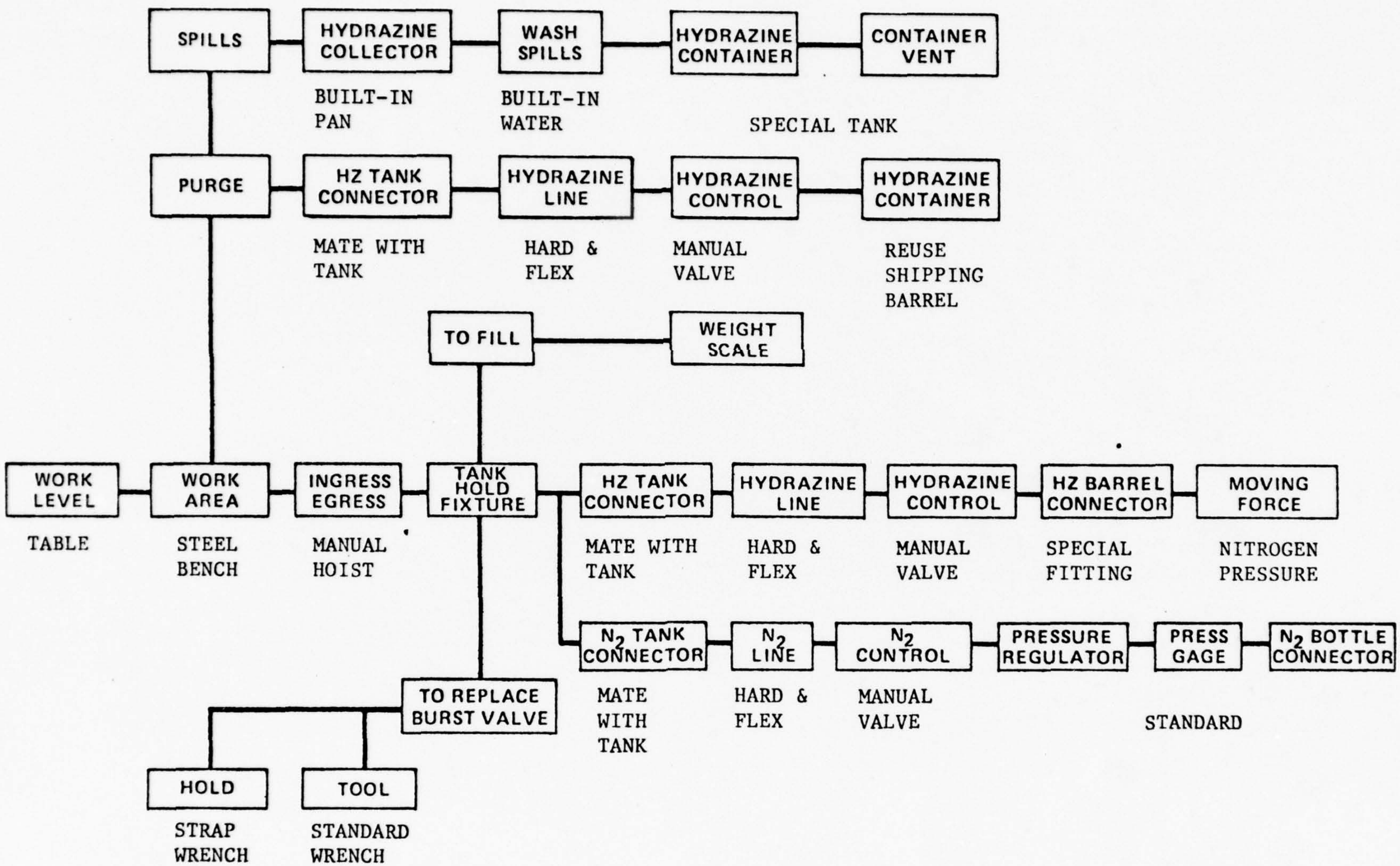

FIGURE 15: CANDIDATE SYSTEM #9, CF_{α} = .859, (RANK = 1)

3.6.2 Optimal CF for Parameter Ranges

At this point a search was made of the design space. A closed form algorithm[27] that combines a binary search method with elements of a network search was employed. At the time of this study the software was not fully developed, and hence the achievement of the maximum CF within the design space is not certain. However a CF of 0.996 was achieved (see Figure 16) with this method, and this compares with the $CF_9 = 0.859$ achieved for the best of the 128 candidates.

Table IX compares the parameters of candidate #9 with those resulting from the design space search. This table can be interpreted to represent potential growth in system performance from the configuration emerging as "best" from among the candidates considered, and "best" for the given parametric ranges identified. The parameter values in the right hand column of Table IX may never be achieved in practice, but they represent performance goals achievable from iteration in the design that change the parameters to those values shown.

To Achieve the theoretic value, CF = .996:

1. production man-hours per unit must be reduced to 499 from 559
2. the number of purchased parts can be increased from 93 to 103 while their mean unit cost must be reduced by $1.10 from $33.70 to 32.60
3. man-hours for servicing the stand must be reduced from 4.0 m.h. to 2.7 m.h.
4. simplicity of procedures must be increased from an index of 6 to 10
5. total number of parts should be reduced by one

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[27]Software developed at the University of Houston for equipment design using this morphology.

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Y 1	Y 2	Y 3	Y 4	Y 5	Y 6	Y 7	Y 8	Y 9	Y10	Y11	Y12	Y13	Y14	Y15	C F
51	45	499	326	270	10	10	7	40	360	103	138	142	45	96	0.9963841816
61	45	499	326	304	10	10	7	40	360	103	138	142	45	96	0.9773090096
61	45	499	326	305	10	10	7	40	360	103	138	142	45	96	0.9768757679
61	45	499	326	306	10	10	7	40	360	103	138	142	45	96	0.9763505842
61	45	499	326	307	10	10	7	40	360	103	138	142	45	96	0.9758529135
61	45	499	345	304	10	10	7	40	360	103	138	142	45	96	0.9751383078
61	45	499	346	304	10	10	7	40	360	103	138	142	45	96	0.9750240789
61	45	499	347	304	10	10	7	40	360	103	138	142	45	96	0.9749098059
61	45	499	326	309	10	10	7	40	360	103	138	142	45	96	0.9748944882
61	45	499	348	304	10	10	7	40	360	103	138	142	45	96	0.9747955770
51	45	499	345	305	10	10	7	40	360	103	138	142	45	96	0.9747050661
61	45	499	350	304	10	10	7	40	360	103	138	142	45	96	0.9745670751
6	45	499	345	306	10	10	7	40	360	103	138	142	45	96	0.9741778824
.1	45	499	355	304	10	10	7	40	360	103	138	142	45	96	0.9739958425
61	45	499	345	307	10	10	7	40	360	103	138	142	45	96	0.9736822117
51	45	499	326	313	10	10	7	40	360	103	138	142	45	96	0.9730054987
61	45	499	364	304	10	10	7	40	360	103	138	142	45	96	0.9729676060
61	45	499	345	309	10	10	7	40	360	103	138	142	45	96	0.9727237864
61	45	499	364	305	10	10	7	40	360	103	138	142	45	96	0.9725343643
61	45	499	364	306	10	10	7	40	360	103	138	142	45	96	0.9720091806
61	45	499	364	307	10	10	7	40	360	103	138	142	45	96	0.9715115099
61	45	499	345	313	10	10	7	40	360	103	138	142	45	96	0.9708347969
51	45	499	383	304	10	10	7	40	360	103	138	142	45	96	0.9707969484
61	45	499	364	309	10	10	7	40	360	103	138	142	45	96	0.9705530846
61	45	499	383	305	10	10	7	40	360	103	138	142	45	96	0.9703637067
61	45	499	383	306	10	10	7	40	360	103	138	142	45	96	0.9698385230
61	45	499	383	307	10	10	7	40	360	103	138	142	45	96	0.9693408523
61	45	499	326	321	10	10	7	40	360	103	138	142	45	96	0.9693288648
51	45	499	364	313	10	10	7	40	360	103	138	142	45	96	0.9686640951
61	45	499	402	304	10	10	7	40	360	103	138	142	45	96	0.9686262465
51	45	499	383	309	10	10	7	40	360	103	138	142	45	96	0.9683824269
61	45	499	402	305	10	10	7	40	360	103	138	142	45	96	0.9681930049
61	45	499	402	306	10	10	7	40	360	103	138	142	45	96	0.9676678212
61	45	499	402	307	10	10	7	40	360	103	138	142	45	96	0.9671701505
61	45	499	345	321	10	10	7	40	360	103	138	142	45	96	0.9671581630
51	45	499	383	313	10	10	7	40	360	103	138	142	45	96	0.9664934374
61	45	499	402	309	10	10	7	40	360	103	138	142	45	96	0.9662117251
61	45	499	364	321	10	10	7	40	360	103	138	142	45	96	0.9649874612
61	45	499	402	313	10	10	7	40	360	103	138	142	45	96	0.9643227356
61	45	499	383	321	10	10	7	40	360	103	138	142	45	96	0.9628168036
61	45	499	326	337	10	10	7	40	360	103	138	142	45	96	0.9625464034
61	45	499	326	270	10	8	7	40	360	103	138	142	45	96	0.9623841119
61	45	499	326	270	8	10	7	40	360	103	138	142	45	96	0.9623806293
61	45	554	345	304	10	10	7	40	360	103	138	142	45	96	0.9615521440
51	45	555	345	304	10	10	7	40	360	103	138	142	45	96	0.9613050827
61	45	556	345	304	10	10	7	40	360	103	138	142	45	96	0.9610530655
61	45	499	402	321	10	10	7	40	360	103	138	142	45	96	0.9606451018
51	45	558	345	304	10	10	7	40	360	103	138	142	45	96	0.9605640312
61	45	499	345	337	10	10	7	40	360	103	138	142	45	96	0.9603757016
61	45	561	345	304	10	10	7	40	360	103	138	142	45	96	0.9598229798

FIGURE 16: RESULTS OF FORMAL OPTIMIZATION

Table IX: Comparison of Parameters From Best of 128 Candidates with Those Resulting From Design Space Search

y_k		Candidate #9	Optimal From Design Space
1	Number of connectors	61	61
3	Production man-hours/unit	559	499
11	Number of purchased parts	93	103
4	Mean cost/purchased part	$33.70	$32.60
5	Man-hours for servicing	4.0	2.7
6	Simplicity of procedures	6	10
13	Total number of parts	143	142
8	Simplicity of waste disposal	7	7
9	Ease of shipment	4	4
12	Time to maintain unit	1.38	1.42

6. the time to maintain the unit should stay at its present value, but can be increased without harm to 1.42 minutes/day

4.0 REVIEW OF STUDY

4.1 Problems Encountered in Application

4.1.1 Design Problem Defintion

The SERD[28] is provided to the designers as the basic design information from which they must develop the equipment. At this point many of the basic design decisions have already been determined, and the process of reviewing all data and information was difficult. The Contractor's organization, being large, of necessity had accomplished many of these decisions in a preliminary way. Hence, when the EPU Service Stand Functions identified in Figure 2 revealed operational activities that were not clearly included in the SERD, it became evident that the stand as identified was being developed to handle 72 aircraft (for which it later proved to be efficient- see section 3.5.3). For lesser numbers of aircraft the ingress and egress activities to the F-16 aircraft might be better handled in another manner, but this is not clear from this study.

The SERD also included a preliminary sketch of the Service Stand (see Appendix 1). Such a sketch should not be given the equipment designers since it tends to implant a configuration in the designer's mind which tends to limit his creativity, and possibly the number of candidate systems developed.

The use of hydrazine in a manned aircraft is controversial from the point of view of safety during handling activities. Since limited

[28]Support Equipment Requirements Document 24010, GD/FW. (See Appendix 1)

information existed, the designers tended to simplify these problems when developing the equipment. Hence when protective gear is used by maintenance personnel operation of the levers and valves may prove more difficult than anticipated. At any rate, the service stand is being designed to accommodate protective gear worn by the maintenance personnel.

4.1.2 Implementation of Criteria Function

The development of a criteria function from which to analyze alternative candidate systems has not been standard practice by this Contractor. Hence, for this exercise the designers were placed in a position where they had to check on earlier decisions made elsewhere in the organization. The enlightenment resulting to the designers seemed to bring very positive reaction to the use of the criteria function. The level of insight provided considerably improves understanding of the user problem than might normally have occurred in such a brief time interval.

When the criteria function was used to evaluate the 128 candidate systems, there existed little problem in understanding the meaning of the result. When, however, the design space was searched for better values of the CF, some discussion occurred as to its meaning. Relating the parameters to hardware can be accomplished only in terms of known or defined systems and it was only after some discussion that acceptance was achieved of the notion that the set of parameters resulting from the search of the design space identified potential performance. Hence these parameter values could be viewed as goals for the growth of the EPU Service Stand performance.

4.1.3 Computer Optimization Run

The University of Houston optimization package was programmed to search at broad intervals in certain parameters in the design space and at very small intervals in other parameters. Hence the level of precision of the program was limited at the time of use. However, the resulting $CF_{\alpha} = 0.996$ was considered to be acceptable as a goal since $CF = 1.0$ is the theoretic maximum in the entire space and is not usually achievable even in the theoretic context.

One theory advanced for the achievement of such a high value of CF with this program was the high degree of monotonicity in the mathematical models. The mathematics was relatively straight forward so that large intervals between sampling points did not omit local optima.

4.2 Observed Advantages of This Methodology

4.2.1 Activity Analysis Identified Design Requirements Quickly

The activity analysis resulting in Figure 2 provided immediate recognition of the equipment function and human task requirements to adequately accomplish the desired result. The designers became knowledgeable very quickly.

4.2.2 Activity Analysis Verified SERD

Formal accomplishment of the activity analysis identified those required tasks (both equipment and human) that were not included in the SERD[29] and provided an immediate ability to verify the adequacy of the included tasks.

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[29]Support Equipment Requirements Document.

4.2.3 Assured Formal Accomplishment of Each Design Decision

Formally accomplishing each design decision revealed several areas of importance which might have been overlooked, or accomplished inadequately without the requirement to respond to a given problem area.

This formal sequence of design decisions revealed several areas of importance which might have been overlooked without the requirement to respond to a given problem area.

4.2.4 Provided a Formal Detailed Record of Design Decisions

Accomplishing each step in the design morphology provides a formal record of the decisions made and hence permits subsequent re-evaluation to occur in a much more efficient manner.

4.2.5 Permits Knowledgeable Trade-offs among "Hard" and "Soft" Criteria

The ability to include both hard criteria (such as Cost and Availability) and soft criteria (such as Safety and Ease of Use) in one analytical statement for all criteria inherently has the effect of:

1. Forcing an explicit definition of each criterion
2. Estimating their performance values for the candidate systems
3. Permitting good insight into the redesign requirements for the iterative activities
4. Providing a complete basis for system optimization (i.e. allowing trade-offs in the choice of the best performing candidate system).

4.2.6 Clear Delineation of "best" candidate system becomes available both practically and theoretically.

The choice of the highest CF_{α} from the 128 candidate systems yielding CF values illustrates how existing candidates can be compared. The analysis of the design space shows how a theoretic set of parameter

values can be achieved. The latter can be veiwed as the growth potential of the hardware emerging from the former.

4.2.7 Reduces Risk of Encountering Major Unforeseen Obstacles

This experience indicated that the designers were asking questions in areas of hardware performance and customer requirements before others had considered the problem. Hence the "completeness" of the design morphology reduces the risk of omitting major problem areas.

4.2.8 Integrates Operational and Production Problem Planning

Accomplishing the Input-Output Matrices (see Figures 3, 4, 5, 6) and modelling the criteria serves to integrate the designer awareness of both operational and production problems. This should reduce the number of subsequent field service problems.

4.2.9 Enhanced Designer Confidence in System Performance

The thoroughness with which the designers were forced to make decisions resulted in a high degree of confidence that the emerging EPU Tank Service Stand will perform well in the customer environment.

4.3 Utility of Human Resource Considerations

Inherent throughout the entire project was the "systems" orientation. That is, the need to meet a set of design requirements to satisfy difficult field conditions. Satisfying this need had to be accomplished in a Contractor environment where ample latitude was afforded the designers to accomplish their tasks as they desired them. Hence this morphology offered these designers the opportunity to assure a complete examination of the production-operational problems in a more integrated manner than they normally would have been considered.

It was apparent that the designers had not heretofore considered each of these design decisions in the detail and in the breadth required by the morphology. For example, the accomplishment of the activity analysis would have been restricted to the explicit purging and refilling functions had not the morphology requirement been imposed to look at the tasks to remove, transport, store, service, store, transport, and install the EPU tank. From the instructions provided, only the service function might have been considered. Hence the activity analysis required the designer to consider all the activities of the equipment and the personnel, as opposed to equipment only. Further, personnel activities were identified in the user environment and the problem of safety was explicitly approached both in the human factors context as well as adequacy of equipment performance.

Another major consideration was the manner in which the Criteria Function was developed. This development was approached with the awareness of the "overall" need for meeting design requirements emerging from the Feasibility Study. Hence personnel requirements were inherently included in the criteria (note that X_1, Safety; X_3 Ease of Use; X_5 Producability; X_6 Availability all depend very heavily on human resources and their direct outcomes). The observation is offered that explicit consideration of these criteria would have been highly unlikely without these formalisms. The fact that no explicit comment was made to the designers that human factors should be considered, and that these criteria emerged from their own deliberations in response to the Input-Output Matrix attests to the ability of this morphology to guide the designer objectively. When this occurs the proper inclusion of human factors is self-imposed.

The structure of the criterion models and submodels, as well as the definition of the parameters further reflect the explicit manner in which

human resources influenced the outcome. Submodels heavily dependent on human resources and human factors are Ease of Maneuvering, Ease of Use, simplicity of Waste disposal, and Ease of Shipment.

Parameters heavily dependent on human factors are:

y_3 production man-hours/unit

y_5 man-hours for servicing EPU tank

y_6 simplicity of procedures

y_7 readibility of gages

y_8 simplicity of Waste Disposal task

y_9 Ease of Shipment

y_{12} Time to Maintain Stand

Other constants employed in the CF development that related to human factors are:

LC Learning Curve percentile

L_1 accidental firings/month

L_2 accidental maintenance firings/month

Hence the usefulness of the human resources area to the design of airspace support equipment has been demonstrated. When designers are properly aware of the operational or user problems with the emerging equipment, they will inherently include the effects of human resources even to the extent of explicit quantitative modelling. This study tends to verify this hypothesis.

4.4 Conclusions

4.4.1 The design morphology enhances equipment designer performance by:

1. inducing greatly increased awareness of design problem in user environment

2. more complete requirements definition
3. more complete systems study
4. better integration of "hard" and "soft" criteria
5. better indication of equipment performance improvement areas for future development
6. more rigorous system optimization than is normally accomplished

4.4.2 Better response to user requirements than current practices generally produce was experienced. In particular:

1. USAF can identify result of specific consideration and its affect on resulting equipment
2. Acceptance by USAF during design review was more readily acheved.
3. Easier definition of support equipment needs is achieved

4.4.3 The utility of human resource considerations in the design of this equipment was clearly demonstrated:

1. by forcing a systems orientation and considering the producer's and operational environments in an integrated fashion
2. By broadening the scope of the designer in meeting user needs while simultaneously increasing the technical depth to which he analyzes the problem
3. By integrating the human resources criteria with other performance goals; and human factors models and parameters with other submodels and parameters so that the emerging conclusion is the result of a totally integrated set of performance goals--both from the human resources and the technological domains.

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GENERAL DYNAMICS
Fort Worth Division

SUPPORT EQUIPMENT
RECOMMENDATION DATA (SERD)

DOCUMENT NO. 16PR011
CONTRACTOR General Dynamics
CONTRACT NO. F33657-75-C-0310
END ARTICLE IDENT F-16 A/B
FIG 1 PAGE NO. 1
REVISION NO. Original
DATE

PART I Functional Analysis

A requirement exists at the intermediate level to service the F-16 Emergency Power Unit (EPU) fuel tank with H-70 Hydrazine. Characteristics of the fuel tank include the following:

I. Tank Design

Material - 347 Stainless Steel
Envelope: 8.6" Diameter x 42" long cylinder with elliptical domed ends.
Weight empty: 44.5 pounds
Capacity: 56.0 pounds H-70 Hydrazine
Maximum operating pressure: 400 PSIG
Discharge Mode: Internal piston driven by external source of nitrogen
Fuel Filler Valve: MS33656-2 (modified)
Nitrogen Vent Valve: MS28889-1 (modified)

(Continued on Page 2)

PART II Recommended Solution

Recommend that EPU Fuel Tank Servicing Stand, P/N 16A24010 be developed for servicing the EPU fuel tank. The assembly would include a control console service bench, swing boom and sling, scale, waste collector and connecting hoses (see sketch).

Applicable Design Specifications: 16PS003 General AGE Specification

Applicable Tests: (1) First Article Form-Fit-Function check which will also satisfy system compatibility tests.

ITEM NO.	ITEM NAME
24010	STAND, SERVICING, EPU FUEL TANK

FWP 4774-4-75

Figure 1a

GENERAL DYNAMICS
Fort Worth Division

SUPPORT EQUIPMENT
RECOMMENDATION DATA (SERD)

DOCUMENT NO.	16PR011
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FIG 1 PAGE NO.	2
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PART I Functional Analysis (Continued)

II. Servicing Unit Design Considerations

Servicing to be accomplished from 55 gallon bulk supply of pre-mixed H-70 hydrazine using nitrogen pressure.

Servicing environment to be open shed or continuous ventilation.

Fuel characteristics: H-70 hydrazine is not compatible with certain materials and selective use of materials and liquids in contact with H-70 must be considered.

Safety: H-70 is a non-violent combustible. Collection and controlled disposal of H-70 waste is required. Limits for inhalation of and exposure to H-70 must be considered. All spills and contamination must be thoroughly flushed with water.

Procedure: Defuel the tank and retract the dispensing piston. Replace rupture disc in the fuel supply line. Refuel tank by measuring weight of H-70 in the tank.

NOTE: Preliminary ORLA indicates the requirement for the above maintenance to be at the intermediate level.

ITEM NO.	ITEM NAME
24010	STAND, ~~SERVICING~~ - EPU FUEL TANK

FWP 4774-4-75

Figure 1a

GENERAL DYNAMICS
Fort Worth Division

SUPPORT EQUIPMENT
RECOMMENDATION DATA (SERD)

DOCUMENT NO. 16PR011
CONTRACTOR General Dynamics
CONTRACT NO. F33657-75-C-0310
END ARTICLE IDENT F-16 A/B
FIG 1 PAGE NO. 3
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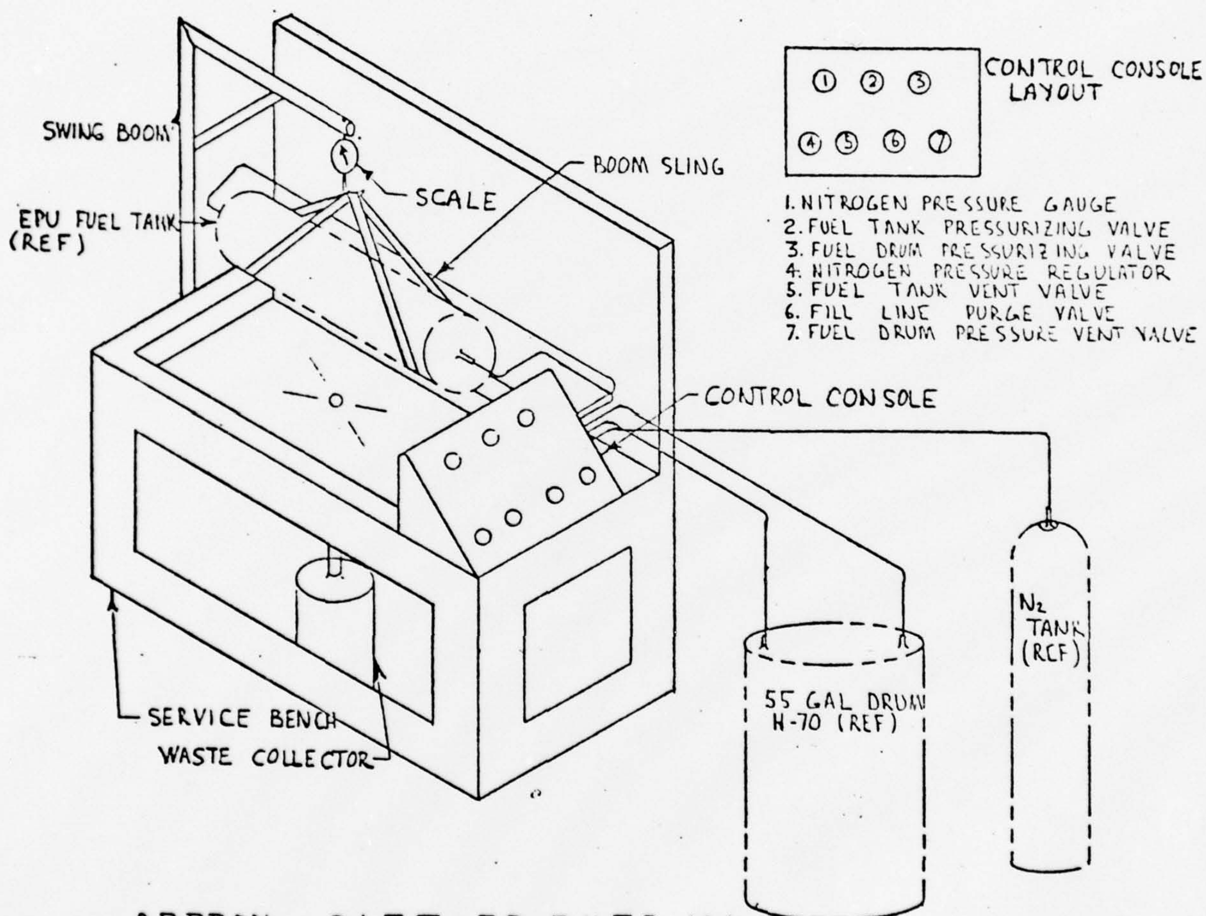

APPROX. SIZE: 72×36×72 IN.
APPROX. WEIGHT: 700 LBS
MATL: STAINLESS STEEL

ITEM NO.	ITEM NAME
24010	STAND, SERVICING, EPU FUEL TANK

FWP 4774-4-75

Figure 1a